ExoPAG SAG 23

The Impact of Exo-Zodiacal Dust on Exoplanet Direct Imaging Surveys

Co-leads

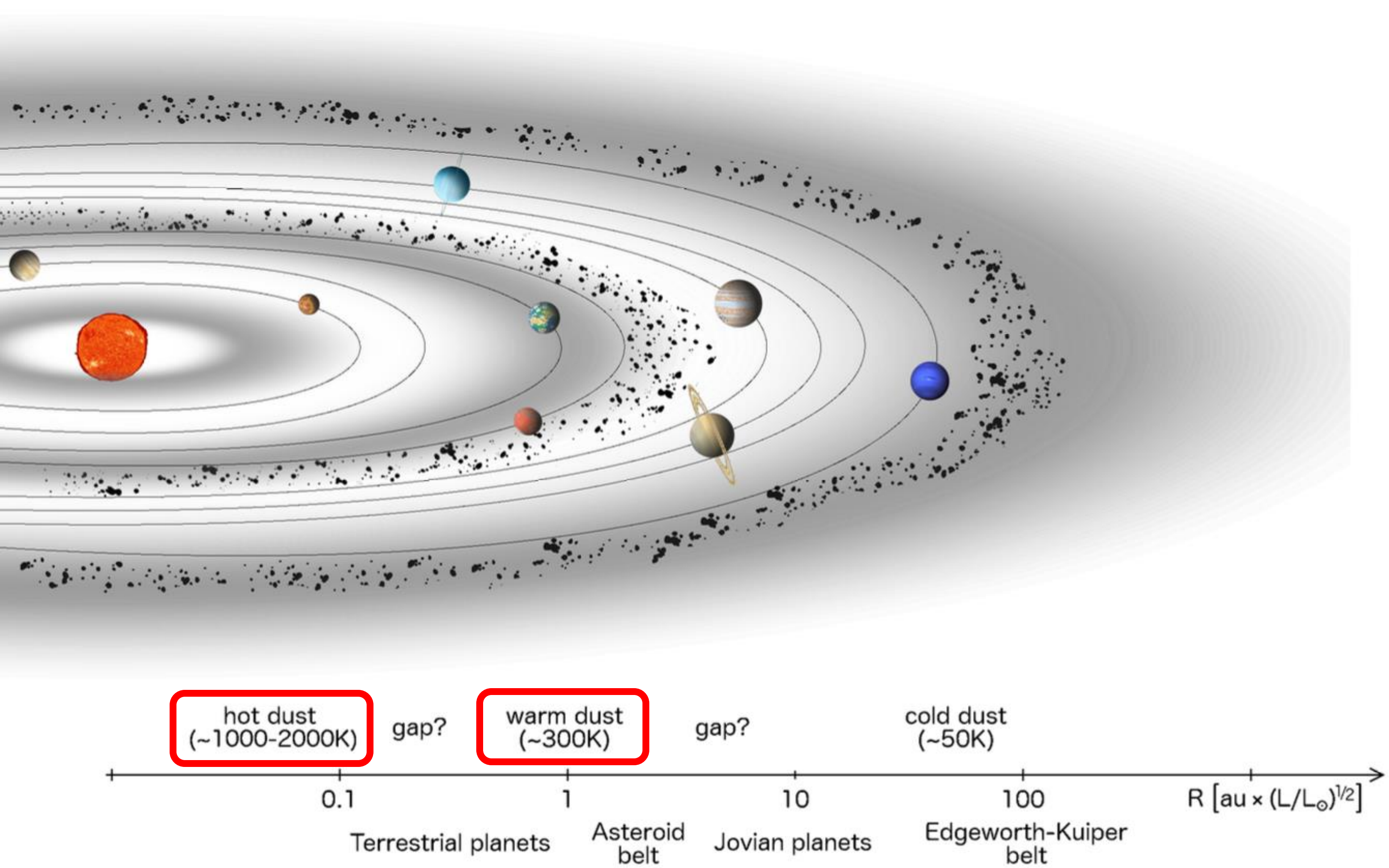
John Debes (Space Telescope Science Institute)

Isabel Rebollido (European Space Agenc, European Space Astronomy Centre)

Yasuhiro Hasegawa (Jet Propulsion Laboratory, California Institute of Technology)

Jet Propulsion Laboratory
California Institute of Technology

What is exozodi? Why do we care?



Credit: S. Ertel

Planetary systems are composed of planets, small bodies (e.g., asteroids, comets), and tiny dust particles

Warm and hot dust are often called as exozodiacal dust, or exozodi in short

Warm dust:
- present around habitable zones
- thermal emission around 10 micron
- becomes noise/confusion sources by scattered light in visible

Hot dust:
- present near the host star
- thermal emission around 1 micron
- introduces coronagraphic leakage in visible

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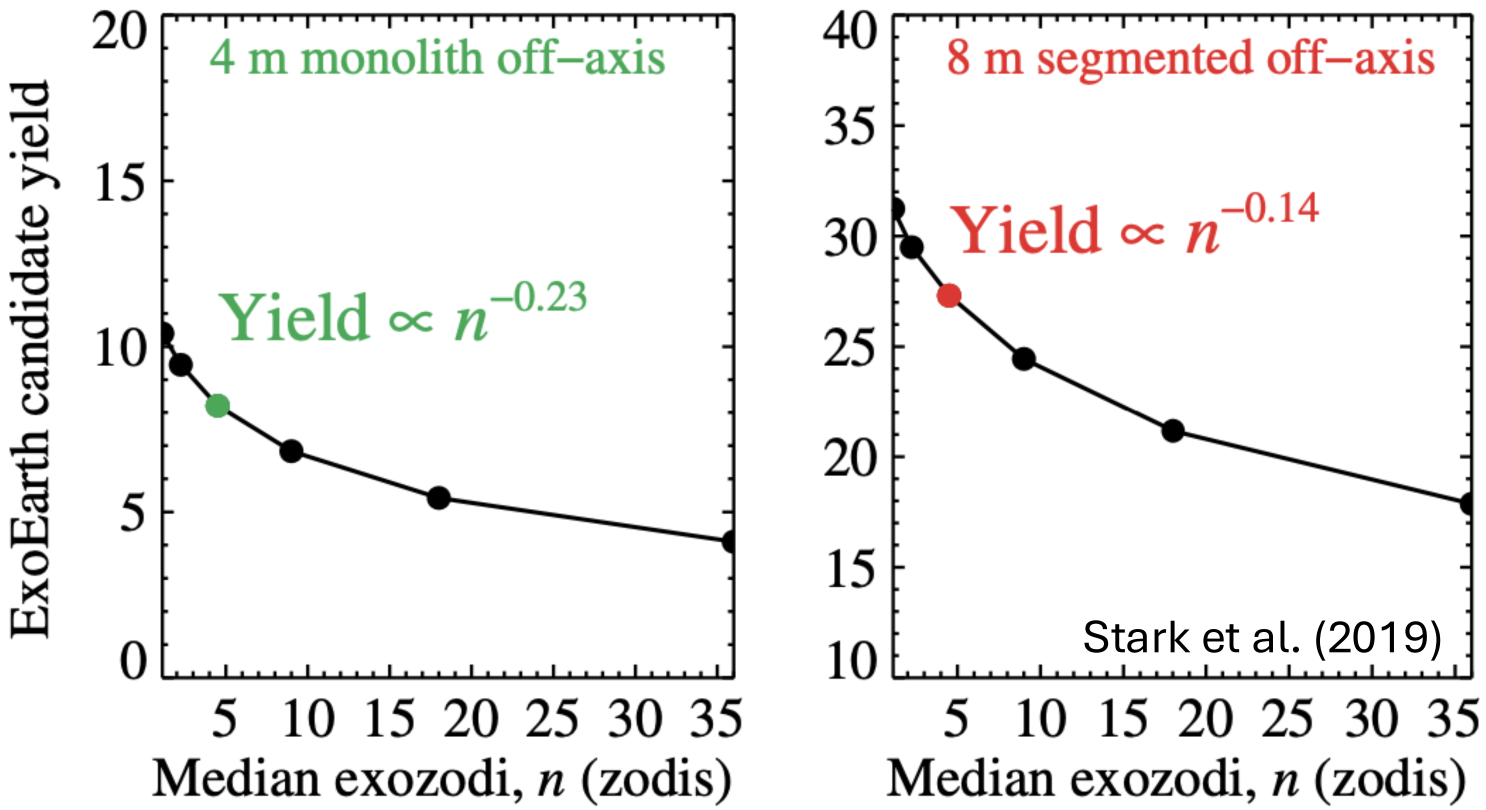

Exozodi is one key parameter to affect yields of Earth-like planets by the Habitable World Observatory (HWO)!!!

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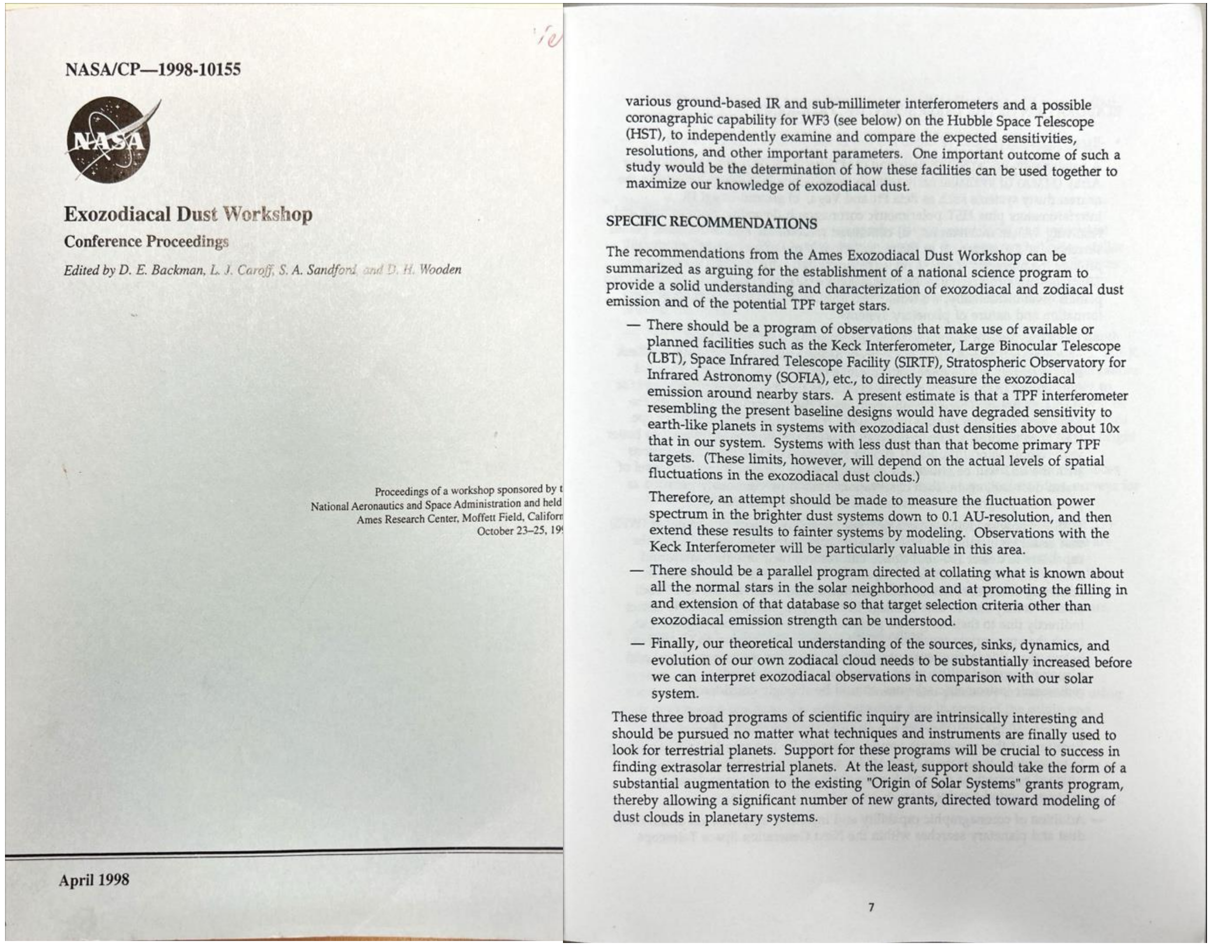
Previous findings/recommendations


NASA/CP—1998-10155

Exozodiacal Dust Workshop

Conference Proceedings

Edited by D. E. Backman, L. J. Caroff, S. A. Sandford, and D. H. Wooden

Proceedings of a workshop sponsored by t
National Aeronautics and Space Administration and held
Ames Research Center, Moffett Field, Califor
October 23–25, 19

April 1998

various ground-based IR and sub-millimeter interferometers and a possible coronagraphic capability for WF3 (see below) on the Hubble Space Telescope (HST), to independently examine and compare the expected sensitivities, resolutions, and other important parameters. One important outcome of such a study would be the determination of how these facilities can be used together to maximize our knowledge of exozodiacal dust.

SPECIFIC RECOMMENDATIONS

The recommendations from the Ames Exozodiacal Dust Workshop can be summarized as arguing for the establishment of a national science program to provide a solid understanding and characterization of exozodiacal and zodiacal dust emission and of the potential TPF target stars.

— There should be a program of observations that make use of available or planned facilities such as the Keck Interferometer, Large Binocular Telescope (LBT), Space Infrared Telescope Facility (SIRTF), Stratospheric Observatory for Infrared Astronomy (SOFIA), etc., to directly measure the exozodiacal emission around nearby stars. A present estimate is that a TPF interferometer resembling the present baseline designs would have degraded sensitivity to earth-like planets in systems with exozodiacal dust densities above about 10x that in our system. Systems with less dust than that become primary TPF targets. (These limits, however, will depend on the actual levels of spatial fluctuations in the exozodiacal dust clouds.)

Therefore, an attempt should be made to measure the fluctuation power spectrum in the brighter dust systems down to 0.1 AU-resolution, and then extend these results to fainter systems by modeling. Observations with the Keck Interferometer will be particularly valuable in this area.

— There should be a parallel program directed at collating what is known about all the normal stars in the solar neighborhood and at promoting the filling in and extension of that database so that target selection criteria other than exozodiacal emission strength can be understood.

— Finally, our theoretical understanding of the sources, sinks, dynamics, and evolution of our own zodiacal cloud needs to be substantially increased before we can interpret exozodiacal observations in comparison with our solar system.

These three broad programs of scientific inquiry are intrinsically interesting and should be pursued no matter what techniques and instruments are finally used to look for terrestrial planets. Support for these programs will be crucial to success in finding extrasolar terrestrial planets. At the least, support should take the form of a substantial augmentation to the existing "Origin of Solar Systems" grants program, thereby allowing a significant number of new grants, directed toward modeling of dust clouds in planetary systems.

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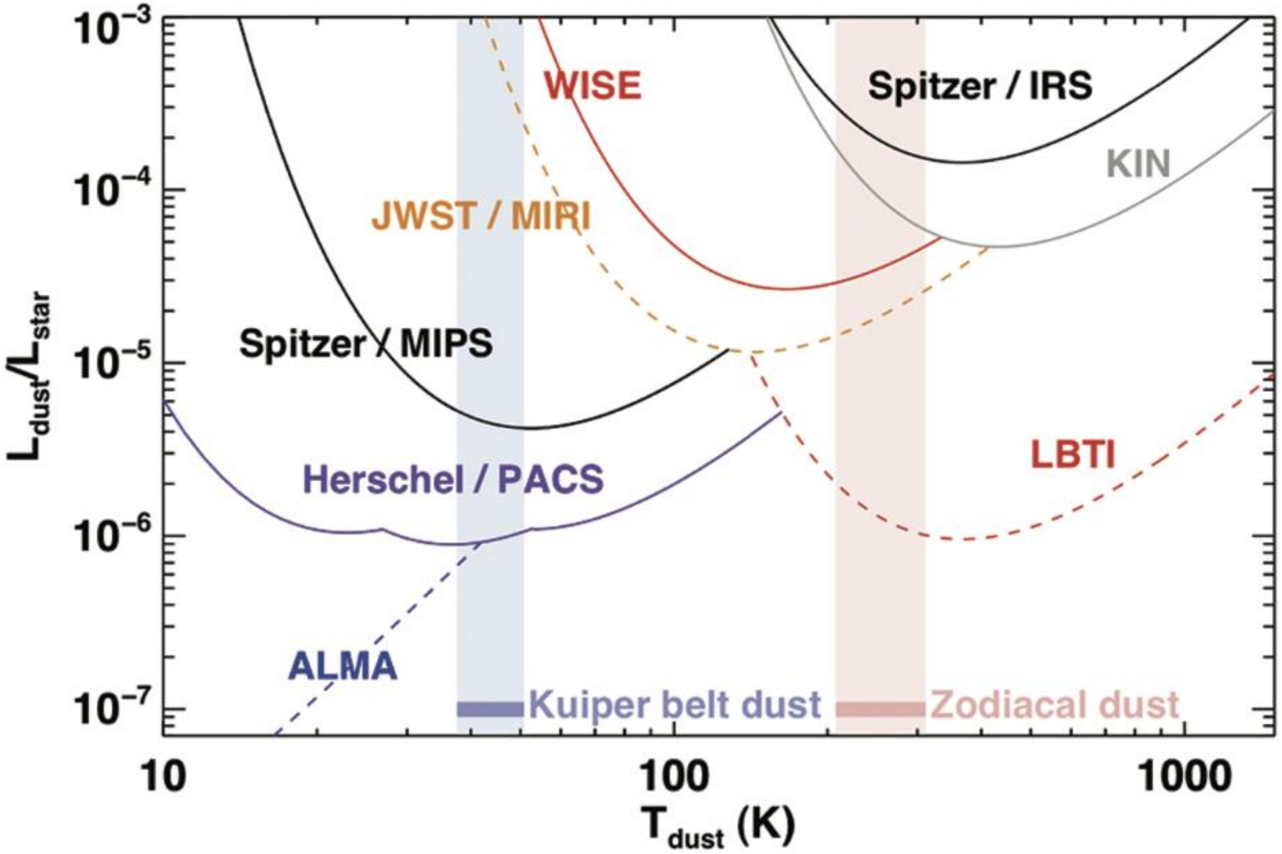
20+ year old recommendations!



Adopted from SAG 1 report (Roberge et al 2012)

The occurrence rate of *warm* exozodi should be constrained by observations with LBTI and other facilities

All other observations available should be used to develop a reliable target selection strategy

Theoretical understanding of the origin of *Solar* zodi should be increased

Focused areas of SAG 23

Theory of Exozodi Sources and Dust Evolution (M. Wyatt)

Pan-Chromatic Radiative Transfer of Exozodis (R. Anche)

Hot Dust (S. Ertel, W. Danchi)

A Catalog of Dusty Systems around Nearby Stars (A. Tanner, S. Ertel)

Solar System Zodi (G. Bryden, N. Turner)

Prioritization of Precursor Observational Studies of Debris Disks/Exozodis for Future Direct Imaging Missions (M. Millar-Blanchaer, W. Danchi)

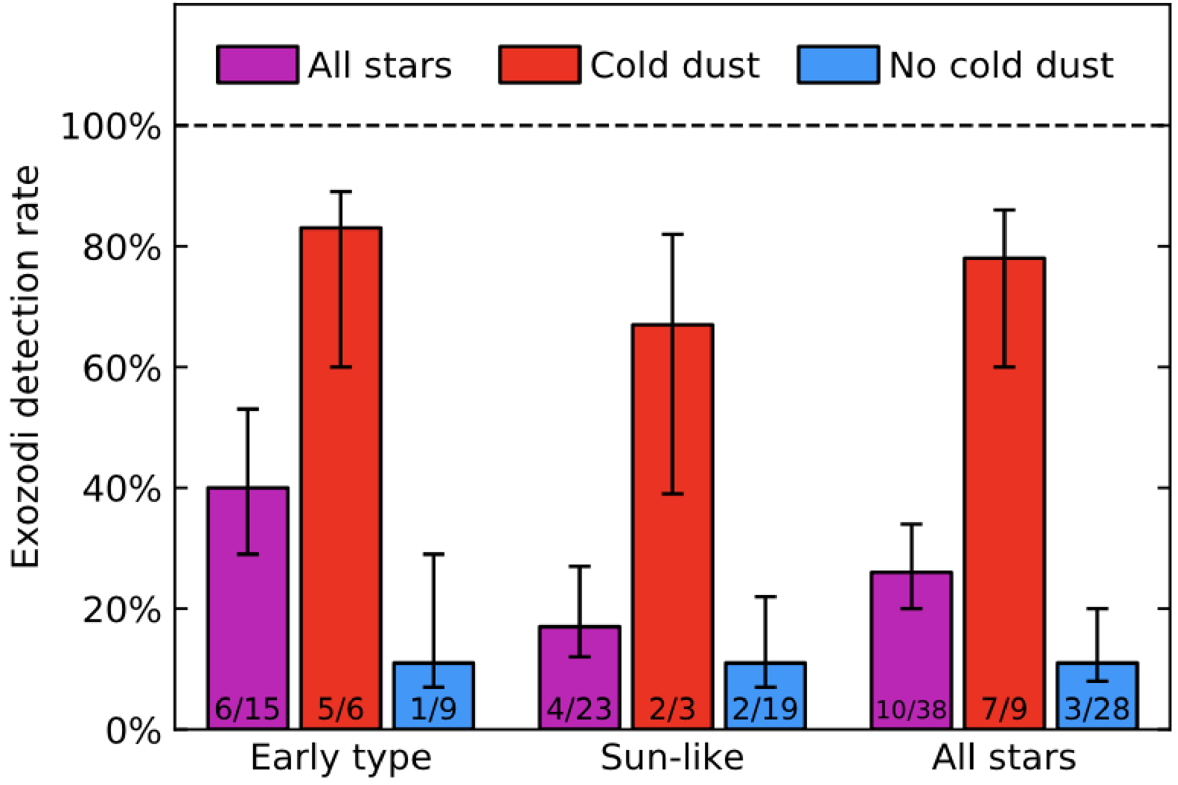
Prioritization of Precursor Theoretical Studies of Debris Disks/Exozodis for Future Direct Imaging Missions (V. Faramaz, S. Dodson-Robinson)

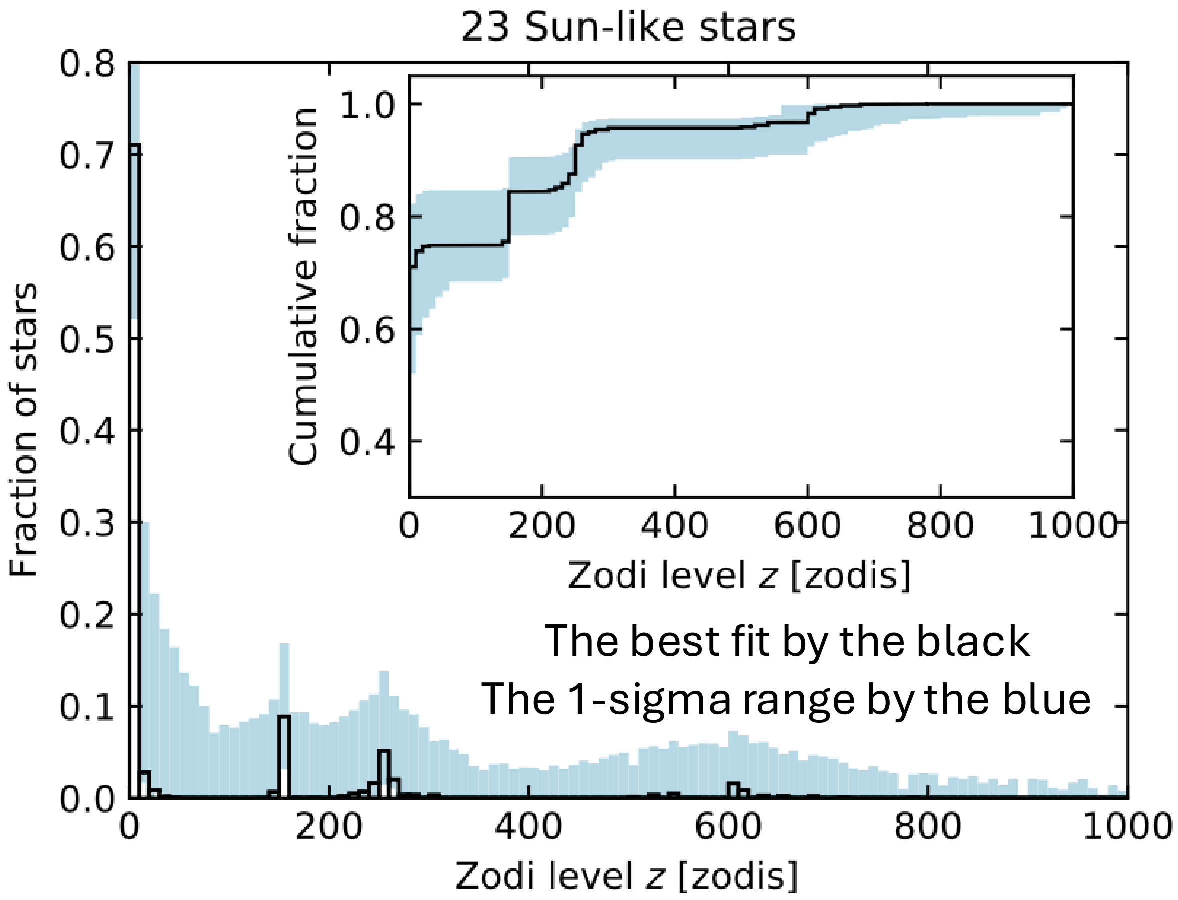
Update and Prioritization of ExEP Gaps relevant to ExoZodis (K. Hoch)

About 40 experts of exozodi, Solar zodi, and debris disks in general contribute to these efforts

HOST survey by LBTI at the *N* band around 10 micron

Ertel et al. 2020



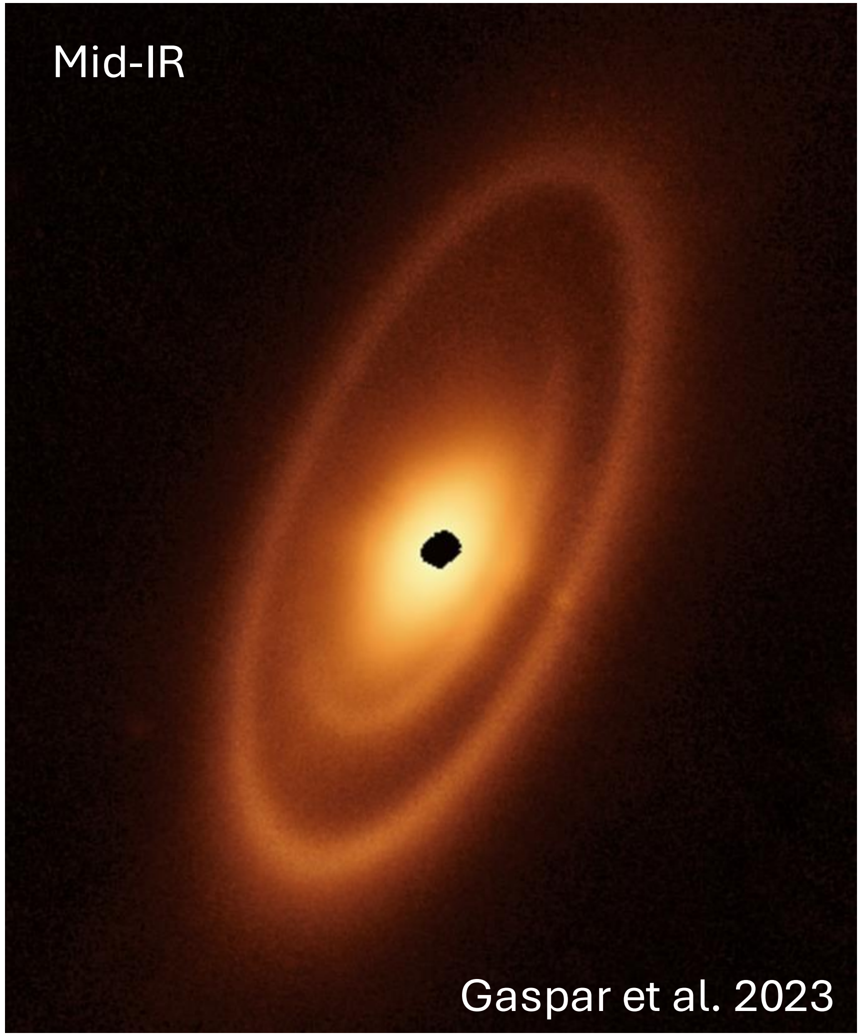


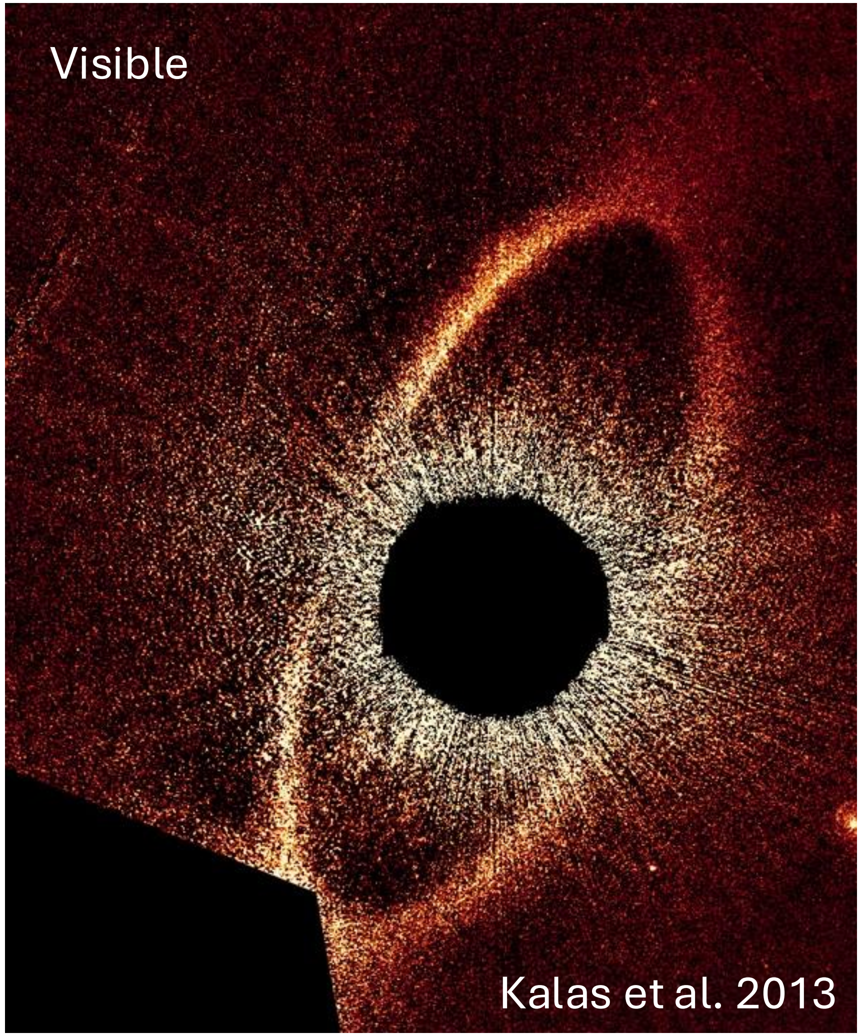
20-40 % of main-sequence stars have detectable *warm* exozodi

A positive correlation with cold debris disks is inferred

The majority of Sun-like stars have relatively low *warm* exozodi levels (best-fit median: 3 zodis)!

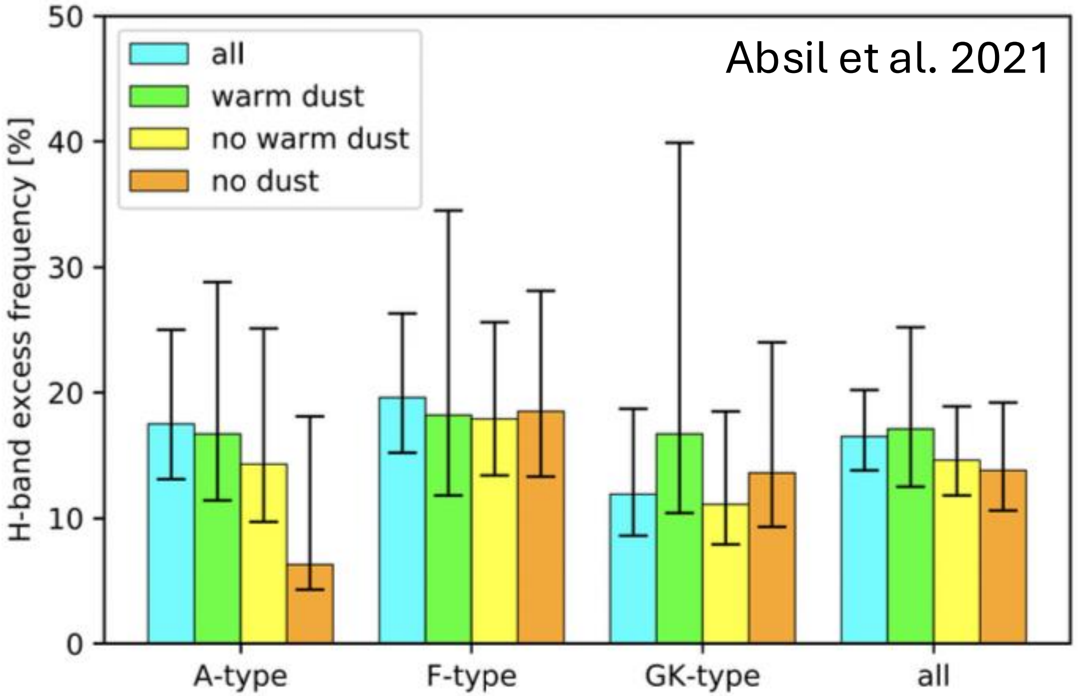
Knowledge gap 1: scattered light from *warm* exozodi at visible





Current large inner working angle of visible observations prevents direct comparison between thermal emission and scattered light from *warm* exozodi

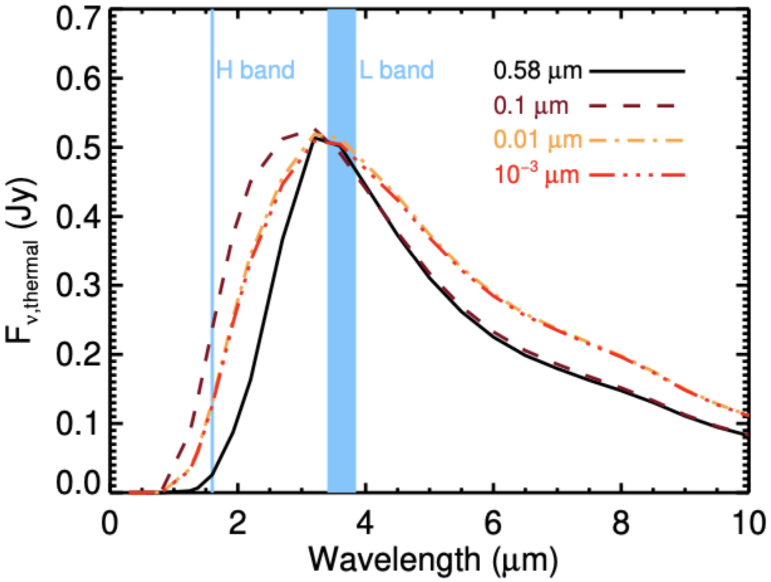
Knowledge gap 2: the presence of *hot* exozodi and coronagraphic leakage



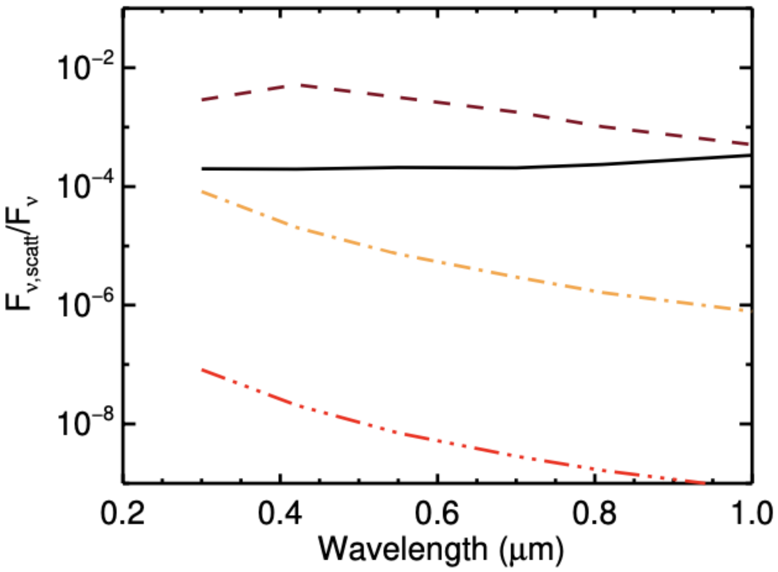
The presence of *hot* exozodi appears not to correlate with stellar spectral type and the presence of other dust in the system

Typical *hot* exozodi flux is around 1% of the stellar flux in the H or K bands

For some stars, hot dust resides at ~lambda/D for HWO, causing coronagraphic leakage, as already suggested by JWST observations



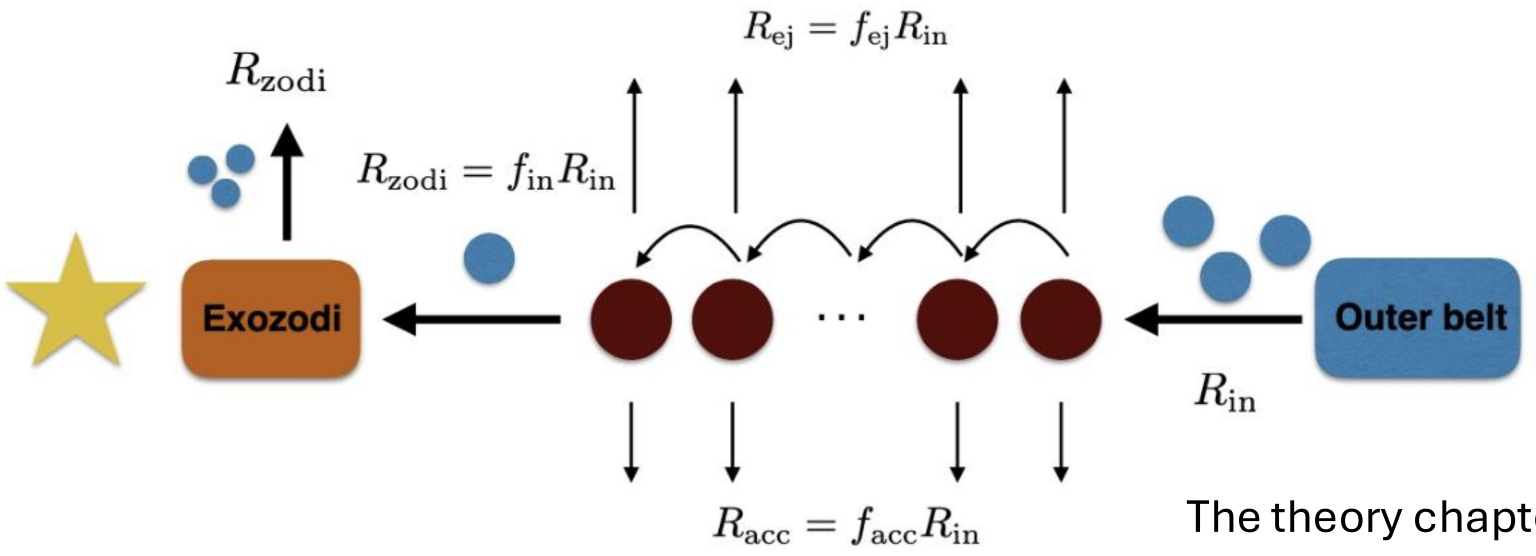
Thermal emission from *hot* Exozodi is relatively insensitive to grain size



Scattered light from *hot* Exozodi is very sensitive to grain size

The hot dust chapter by Ertel et al.

Knowledge gap 3: Poorly constrained origins of *warm* and *hot* exozodis



The theory chapter by Wyatt et al.

Warm exozodi

- Inward drift of cold dust by PR drag possibly interacting with planets
- Inward scattering of exocomets by planets
- Other dynamical processes (e.g., Kozai)

Hot exozodi

- Sublimation of dust
- Magnetic trapping
- Gas drag

Key steps to fill out gap 1: better characterize *warm* exozodi

The precursor observation chapter by Millar-Blanchaer, Danchi et al.

- **Complete LBTI HOST survey**
  Due to the funding limitation, only 38 of the 68 targets were observed by the original survey
  A renewed survey could provide a constraint on the median exozodi level **three times** better than now

- **Use the Coronagraph Instrument mounted on the Roman Space Telescope**
  the observations may be well suited to detect a significant number of exozodiacal disks and could place upper limits **lower than** LBTI

Key steps to fill out gap 2: better characterize *hot* exozodi

The hot dust chapter by Ertel et al.

- **Observe and characterize hot exozodi with MATISSE**
  MATISSE's **denser u-v-coverage** and **spectral resolution** will provide improved constraints on the properties of hot exozodi (e.g., **dust geometry** including asymmetric structures in the spatial distribution, **spectral features**)

- **Explore luminosity function and variability with NOTT**
  NOTT will detect **ten to fifty times** more tenuous hot exozodi systems than currently possible and thus to derive a real luminosity function

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Key steps to fill out gap 3: improve our understanding of exozodi

The precursor theory chapter by Faramaz et al. & the pan-chromatic radiative transfer chapter by Anche et al.

- **Develop predictable models for the properties of exozodi**
  Conduct a **thorough** parameter study including **various delivering mechanisms** and reveal any relationships between the properties of exozodi and planetary system architectures

- **Develop end-to-end modeling frameworks in which different telescope and instrument designs will be coupled with detailed treatments of dust scattering properties**
  Construct **sophisticated grain models** based on experimental measurements and observations and infuse into **radiative transfer simulations** to better characterize observed properties (e.g., speckle shape and size) of exozodi in visible

Completed and planned activities

- **One-day workshop (**Sept, 15, 2023 at STScI)
  About 20 in person and 50 remote participants with a good mixture of career levels
  Active discussions with nearly equal interests on each focused areas including talks from community members

- **Documentation**
  The hot dust chapter was submitted to PASP in Oct, 2024
  Updated recommendations on the ExEP Gap list (the science gap list chapter by Hoch et al.)
  The final report with 8 chapters will be delivered in March, 2025 and accessible to the community via the ExoPAG website and astro-ph

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